ACADEMIA

Accelerating the world's research.

The Chihuahuan Desert: A Binational Conservation Response to Protect a Global Treasure

Helen Poulos

Encyclopedia of the World's Biomes

Cite this paper

Downloaded from Academia.edu

Get the citation in MLA, APA, or Chicago styles

Related papers

Download a PDF Pack of the best related papers

Conservation and status of the fish communities inhabiting the Río Conchos basin and middl…
Gary Garrett

CONSERVATION OF DESERT WETLANDS AND THEIR BIOTAS / CONSERVACIÓN DE HUMEDALES DESÉR…
Evan Carson, Mauricio De la Maza Benignos

Integrating Environmental Flows into Multi-Objective Reservoir Management for a Transboundary, Wa…
Belize Lane

The Chihuahuan Desert: A Binational Conservation Response to Protect a Global Treasure

Mark K Briggs, RiversEdge West, Tucson, AZ, United States
E Alejandro Lozano-Cavazos, Antonio Narro University, Saltillo, Mexico
Helen Mills Poulos, College of the Environment, Wesleyan University, Middletown, CT, United States
Javier Ochoa-Espinoza, Protected Area for Flora and Fauna of Maderas del Carmen, Chihuahua, Mexico
J Alfredo Rodriguez-Pineda, WWF-Mexico, Chihuahua, Mexico

© 2019 Elsevier Inc. All rights reserved.

Introducing the Chihuahuan Desert 1
Threats 3
Habitat Loss and Fragmentation 3
Climate Change 3
Changes in Wildfire Regimes 4
Deterioration of Freshwater Ecosystems 4
Conservation Response 4
International 5
National 5
Local—Examples From the Field 6
Working with private landowners 6
Protecting freshwater ecosystems 8
Looking to the Future 10
References 12

Abstract

Occupying over 140,000 km^2 (54,000 mi^2), the Chihuahuan Desert is the second largest desert in North America and includes much of the Mexican states of Chihuahua, Coahuila, Durango, Zacatecas and San Luis Potosi, as well as large parts of New Mexico and the Trans-Pecos region of Texas in the U.S. Of the arid ecoregions in the world, the Chihuahuan Desert ranks at the top with regard to plant diversity. This incredible ecoregion is also noted for its endemism, with over 670 species of plants and nearly half of its freshwater fish found nowhere else in the world. The Chihuahuan Desert faces a variety of threats, including habitat loss and fragmentation, climate change, changing wild fire regimes, and deterioration of its freshwater resources. We review these threats as well as the conservation response to them, which includes a diversity of public-private partnerships operating at regional to local scales. We conclude with a summary of conservation priorities for the future, which highlights the importance of a binational response that directly addresses the main drivers of decline, is based on lessons learned from past conservation efforts, expands natural resource monitoring, and builds on momentum of small scale conservation efforts for greater impact.

Introducing the Chihuahuan Desert

The Chihuahuan Desert is the most biologically diverse desert in the Western Hemisphere and one of the most diverse arid regions in the world (Cotera et al., 2004). From north to south, the ecoregion extends nearly 1500 km (932 miles), with its northern extent just south of Albuquerque, New Mexico to its southern extent in the Trans-Mexican Volcanic Belt, which lies just 250 km (155 miles) north of Mexico City. Occupying over 140,000 km^2 (54,000 mi^2), the Chihuahuan Desert includes much of the states of the Chihuahua, Coahuila, Durango, Zacatecas and San Luis Potosi, as well as large parts of New Mexico and the Trans-Pecos region of Texas, making it the second largest desert in North America (Fig. 1).

The Chihuahuan Desert has hot summers and cool to cold, dry winters. The moisture sources that affect the Chihuahuan Desert's climate most are the Sea of Cortez and Gulf of Mexico. Surrounding mountain masses and the position of the desert in the center of the continent results in little frontal precipitation. As a result, the Chihuahuan Desert has a high percentage of its precipitation falling in the form of monsoonal rains during the summer months. With average annual precipitation typically ranging from 150 to 500 mm (6 to 20 in.), this desert has more rainfall than many warm desert ecoregions (Schmidt, 1979).

Distinctive habitat types in the Chihuahuan Desert include yucca woodlands, playas, gypsum dunes, and a diverse array of freshwater habitats. Isolated by the high mountains of the Sierra Madre Oriental, the Sierra Madre Occidental, and the Arizona-New Mexico Mountains, the portion of the Chihuahuan Desert of high Mexican Plateau is rich with endemic species, particularly plants and reptiles (Hernandez and Barcenas, 1995; Gómez-Hinostrosa and Hernández, 2000). For example, a recent study found endemic plants comprising 67 families, 263 genera, 671 species and 155 infraspecific taxa (73 subspecies, 79 varieties and 3 additional hybrids), making a total of 826 taxa (Villarreal-Quintanilla et al., 2017). These results align well with an earlier study that

https://doi.org/10.1016/B978-0-12-409548-9.11966-9

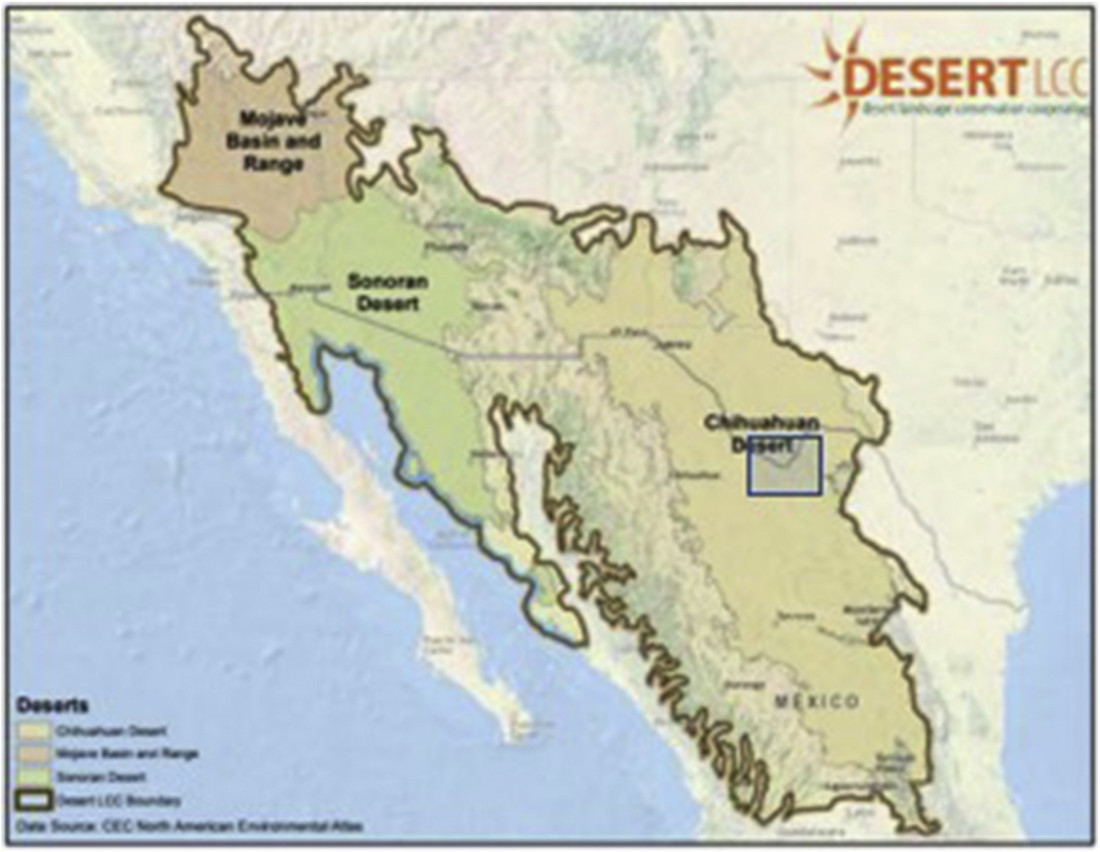

Fig. 1 Location and extent of the Chihuahuan Desert ecoregion alongside two of its 'sister' North American deserts, the Mojave Desert and Sonoran Desert. The binational region of Big Bend (discussed later on in this article) is delineated by square. Map from the Desert Landscape Conservation Center.

documented over 1000 endemic plant taxa (Johnston, 1977). Highlands have significantly higher woody plant diversity than lowlands throughout the region, and physiography is a major control on woody plant diversity (Montaña, 1990; Gómez-Hinostrosa and Hernández, 2000; Poulos and Camp, 2010). Tall mountains and rugged topography provide habitat characteristics conducive to vertical stacking of biotic communities, which amplifies the biodiversity of the Chihuahuan Desert's montane ecosystems.

Grasslands comprise a small part of the Chihuahuan Desert but are vital to the biological diversity of the ecoregion (PACP-Ch, 2011). Characteristic grasses of the Chihuahuan Desert are tobosa (*Pleuraphis mutica*) and black grama (*Bouteloua eriopoda*) but other common species include alakali sacaton (*Sporobolus airoides*), big alkali sacaton (*S. wrightii*), mesa dropseed (*S. flexuosus*), blue grama (*B. gracilis*), sideoats grama (*B. curtipendula*), hairy grama (*B. hirsuta*), slender grama (*B. filiformis*), chino grama (*B. brevista*), spruce top grama (*B. chondrosioides*), bush muhly (*Muhlenbergia porteri*), several three awns (*Aristida* spp.), and fluff grass (*Dasyochloa pulchela*) (Johnston, 1977; Dinerstein et al., 2000).

Reptile diversity in the Chihuahuan Desert is impressive and well-documented (UTEP Museum, n.d.; Prival and Goode, 2014; Cruz-Elizalde et al., 2014). Two orders of reptiles occur in the Chihuahuan Desert: Testudines (turtles) (Fig. 2) and Squamata (lizards and snakes), with the latter order being particularly diverse. Seven families of lizards have been recorded in the Chihuahuan Desert region. The Gila Monster (*Heloderma suspectum*) is one of only two known poisonous lizards worldwide, though its range barely overlaps with the Chihuahuan Desert (touching the northwestern portion near the Arizona/New Mexico border) with most of its range is in the Sonoran Desert. The grand majority of snake species (suborder Serpentes) in the Chihuahuan Desert are in the family Colubridae, which are nonvenomous. In contrast, the coral snake (Family Elapidae) is venomous with two species occurring in the eastern and western fringes of the Chihuahuan Desert: the Eastern Coral Snake (*Micrurus fulvius*) and the Western Coral Snake (*Micrurus euryxanthus*). The more familiar venomous snakes in the region are the pit vipers (Family Viperidae), which includes five rattlesnakes. The name comes from the presence of a pit between the eyes and nostrils that contains receptors for infrared radiation (heat) that allow tracking of warm-blooded prey.

A striking number of endemic freshwater fish occur in the Chihuahuan Desert—nearly half of the species in the ecoregion are either endemic or of limited distribution. Most of these are relict pupfish (Cyprinodontidae), shiners (Cyprinidae), livebearers (Poeciliidae), and Mexican livebearers (Goodeidae) found in isolated springs in the closed basins of the region. One of the better-known aquatic basins is Cuatro Ciénegas in central Coahuila, but other significant areas of endemism include the Rio Nazas, Media Luna, the Guzman Basin (Miller, 1977; Minckley, 1984; Minckley et al., 1991), and the Pecos Plain. At least one undescribed species

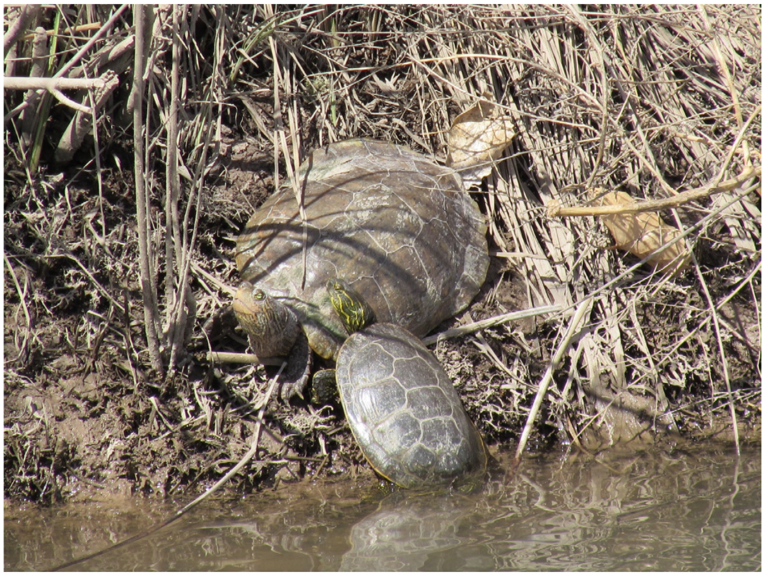

Fig. 2 Two turtle species of the Chihuahuan Desert biome that are of conservation concern: western painted turtle (*Chrysemys picta*) (lower) and the Big Bend slider (*Trachemys gaigeae*) (upper). Photo by John Karges, The Nature Conservancy.

of trout (*Oncorhynchus* sp.) occurs in the Chihuahuan Desert ecoregion as an evolutionary isolate in headwater streams in the Sierra Madre Occidental (Hendrickson et al., 2006).

There are also far-ranging large mammals such as Carmen Mountain white-tailed deer (*Odocoileus virginianus carminis*), desert mule deer (*Odocoileus hemionus crooki*), bighorn sheep (*Ovis canadensis mexicana*), elk (*Cervus canadensis*), pronghorn (*Antilocapra americana mexicana*), black bear (*Ursus americanus*), mountain lion (*Puma concolor*), and, jaguar (*Panthera onca*) and, perhaps, some released Mexican wolves (*Canis lupus baileyi*). Over 350 bird species have been recorded in this region, and the river corridor serves as a major thoroughfare and/or stopover for birds (Brush, 2005) and other species (e.g., the Monarch butterfly) that migrate between the Americas.

Threats

Of the many threats that face the Chihuahuan Desert, several standouts seem particularly critical and will need to be addressed as part of a multisector, binational response in the future.

Habitat Loss and Fragmentation

Outright loss of habitat and habitat fragmentation throughout the Chihuahuan Desert has been driven by a variety of factors, including agriculture, urbanization, road construction, amongst others. The conversion of native grassland ecosystems to agriculture has been particularly severe. The rate of grassland conversion varies with location. In the central and northern valleys of the state of Chihuahua, analysis of satellite imagery and on-the-ground observations revealed that more than 69,000 ha (170,500 acres) were converted to agriculture between 2006 and 2011. This amounts to an expansion of the agricultural footprint in this region by an annual rate of 6.04% (Pool et al., 2014). If this continues unabated, it has been estimated that grassland habitat in central Chihuahua will disappear completely by 2025 (NABCI, 2016).

Climate Change

One of the few certainties regarding the effects of global climate change is that wet areas will tend to get wetter and dry areas will become drier. There is no more dramatic evidence of this phenomenon than the Chihuahuan Desert. From 1993 to 2005, after the relatively wet years of 1990–1991, the portion of the Chihuahuan Desert within the Rio Grande/Bravo (RGB) (this binational river is often referred to as the 'Rio Grande' in the U.S. and 'Rio Bravo' in Mexico. Hence, Rio Grande/Bravo (RGB)) watershed suffered the most extreme drought in 100 years. The drought not only undermined economic growth and severely stressed the natural environment, it fueled tensions between the US and Mexico over allocation of internationally shared waters (e.g., the Rio Grande/Rio Bravo, which constitutes the international border in the eastern half of the Chihuahuan Desert).

In an analysis of long-term climate data in the northern portion of the Chihuahua Desert, temperatures are projected to continue to increase throughout the 21st century and, depending on future emissions and other factors, the warming may accelerate

(McRoberts and Nielsen-Gammon, 2010). Average temperatures are expected to rise 2 °C–3 °C (3 °F–5 °F) by the middle of the 21st century (Nielsen-Gammon, 2008). When considering interannual variability, even cool years during the middle of the 21st century will be normal or above normal relative to current temperatures.

The effects of climate change on precipitation are much less predictable, with models suggesting a slight decrease in precipitation across much of the Chihuahuan Desert region in Texas. However, changes in precipitation are projected to be much smaller than the natural variability. For a given amount of precipitation, evaporation increases with increased temperatures and this will make future droughts even if rainfall stays the same. Additionally, increased evaporation will create dwindling water supplies and the projected increase in population will further decrease water. This is eye-opening forecast because the majority of precipitation falls during the warm season. Therefore, the availability of water will depend more and more on cool season precipitation, which is normally sparse in this region (McRoberts and Nielsen-Gammon, 2010).

Changes in precipitation and temperature affect biophysical and chemical processes with cascading impacts on all Chihuahuan Desert ecosystems, and with consummate effects on people and wildlife, alike. For example, warmer water temperatures, increased salinization, and low dissolved oxygen, such as are projected for the Rio Grande Basin (Llewellyn and Vaddey, 2013), may increase the likelihood that nonnative aquatic species will invade (Rahel and Olden, 2008; Bond et al., 2008). Longer, more severe droughts could decrease runoff and eliminate ephemeral lakes and spring pools, as well as drive perennial streams toward intermittent flow, and intermittent streams to ephemeral (Grimm et al., 1998; Garssen et al., 2014).

Changes in Wildfire Regimes

Fire regimes in the region have shifted dramatically over the past two centuries. Prior to Euro-American settlement, frequent, low-intensity surface fire prevailed across most of the dry woodlands and forests of this region (Sakulich and Taylor, 2007; Poulos et al., 2009; Poulos et al., 2013). Starting in the early 20th century, fire exclusion from livestock grazing and then active fire suppression led to a precipitous decline in fire frequency (Swetnam and Betancourt, 1990). Today, more than a century of mounting fuel loads in combination with intensified aridity have sparked a regional surge in catastrophic fires (Dennison et al., 2014; Westerling et al., 2006; Abatzoglou and Williams, 2016). Like the fire suppression era before it, this new fire regime is well outside the historic range of variation for most grassland, semiarid woodland and forest types in the American Southwest and has contributed to large-scale shifts in species composition and structure (Poulos et al., 2013).

Deterioration of Freshwater Ecosystems

Water is important in any context, but is particularly so in the Chihuahuan Desert, where access to sufficient water of sound quality is essential to people and native species, alike. Along the international border between Mexico and the U.S., the Binational Big Bend region of the Chihuahuan Desert is named after the characteristic "bend" in the RGB. Along this border region, the mainstem of the RGB, itself, and its second largest tributary, the Rio Conchos (Fig. 3) comprise the region's ecological backbone, providing water, food and shelter for 5.5 million citizens as well as a grand diversity of wildlife. Portions of the RGB river system are estimated to be 150% over-allocated. For example, a study of water supply and demand in the lower RGB basin finds that there will be a 730.3 Mm^3 (592,084 acre-feet per year (ac-ft/yr)) supply shortfall (demand minus supply) by 2060, with an additional 106.6 Mm^3 (86,438 ac-ft/yr) added to that amount as a result of climate change impacts (BOR, 2013). Groundwater is faring no better; 43 of the Desert's aquifers are overexploited as they are pumped to supply irrigated agriculture, whose footprint has expanded as more and more native grasslands are converted to cropland.

Although flow from the Rio Conchos rejuvenates the hydrology of the RGB through Big Bend, the river's hydrograph is highly modified and reflects the impacts of impoundment, channelization, over-allocation of water, and fragmentation (Everitt, 1993). Along the RGB in Big Bend, declines in mean and peak stream flow, combined with a relatively unchanged sediment supply and the invasive giant cane (*Arundo donax*), which has established in dense, almost impenetrable stands along channel margins, have fostered aggradational processes (processes that increase surface elevation as a result of deposition of sediment) that bury high quality native aquatic and riparian habitat (Dean and Schmidt, 2013). Many small tributaries of the RGB system are not faring any better. For example, Terlingua Creek, whose watershed lies just north of the international border in Big Bend, was once a "bold running stream, studded with cottonwood timber and alive with beaver" (BIBE, historical archives). However, mining and agricultural activities during the late 19th and early 20th centuries precipitated the loss of these riparian forests and the many species that depend on them for their survival. Similar changes have occurred in many streams across the Chihuahuan Desert ecoregion.

Conservation Response

High species richness, large numbers of endemic species, and presence of globally rare habitats has identified the Chihuahuan Desert as one of a group of 200 high priority ecoregions worldwide (Olson and Dinerstein, 2002). The conservation response to protect the natural resources of this rich ecoregion ranges from global recognition to binational declarations and initiatives between Mexico and U.S. to smaller scale efforts conducted by a variety of public-private partnerships. Selected initiatives in each of these categories are presented below.

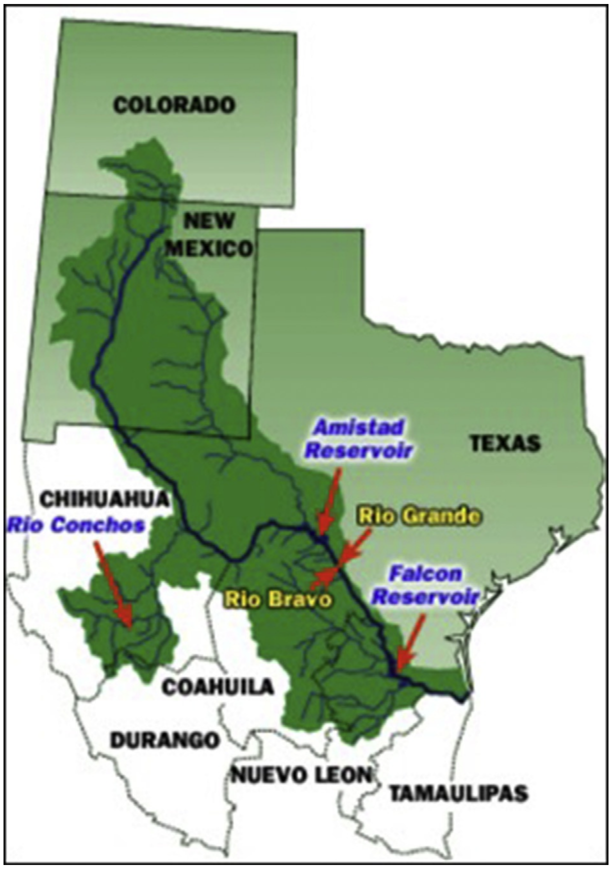

Fig. 3 Idealized map of the Rio Grande/Bravo (RGB) basin, which overlaps substantially with the Chihuahuan Desert biome and whose freshwater ecosystems are critical to sustaining this ecoregion's native species and citizens.

International

There are several international agreements associated with key parts of the Chihuahuan Desert that, in and of themselves, do not protect the areas they are associate with yet serve as rallying points for attracting a diverse governmental and nongovernmental conservation response. One such example is the Ramsar Convention of Wetlands, which is an international treaty (signed in the city of Ramsar, Iran in 1971) that supports the conservation and sustainable use of wetlands globally. In the Mexican portion of the Chihuahuan Desert, there are several important wetlands sites that are recognized by the Ramsar Convention, including: Laguna de Babicora, Rio San Pedro-Meoqui (Fig. 4), Laguna La Juanota, Humedales de Guachochi, Manantiales Geotermales de Julimes, and the Área de Protección de Flora y Fauna Cuatrociénegas in the state of Coahuila.

Several binational declarations and benchmarks between the U.S. and Mexico underscore the importance of protecting the Chihuahuan Desert's treasured natural resources, particularly along the desert's greater binational region of Big Bend. Although nonbinding, these agreements serve to highlight the Chihuahuan Desert's border region as a binational conservation priority and have attracted a diversity of partnerships and funding that are helping to protect this key portion of the Chihuahuan Desert in the long-term. These binational declarations and benchmarks, include:

2000	Joint declaration signed by Bruce Babbitt (Secretary of State, U.S.) and Julia Carabias (Secretary of Environment, Mexico) '. . . to improve and conserve the natural resources of the Rio Grande/Río Bravo and associated habitats.'
2009	A joint declaration by the U.S. Secretary of the Interior Ken Salazar and Mexican Minister of Environment and Natural Resources Juan Elvira to conserve this region's important and diverse natural resources.
2010	Joint Statement from President Barack Obama and President Felipe Calderón that recognized the 'extraordinary biological diversity' of the Big Bend region, committing their respective agencies "to manage the region in a way that enhances security and protects these areas for wildlife preservation, ecosystem restoration, climate change adaptation, wildland fire management, and invasive species control."

National

Within the portion of the Chihuahuan Desert that lies in Mexico, the Mexican government has established a mosaic of eight protected natural areas that are managed by Comisión Nacional de Áreas Naturales Protegidas (CONANP) to protect key scenic and

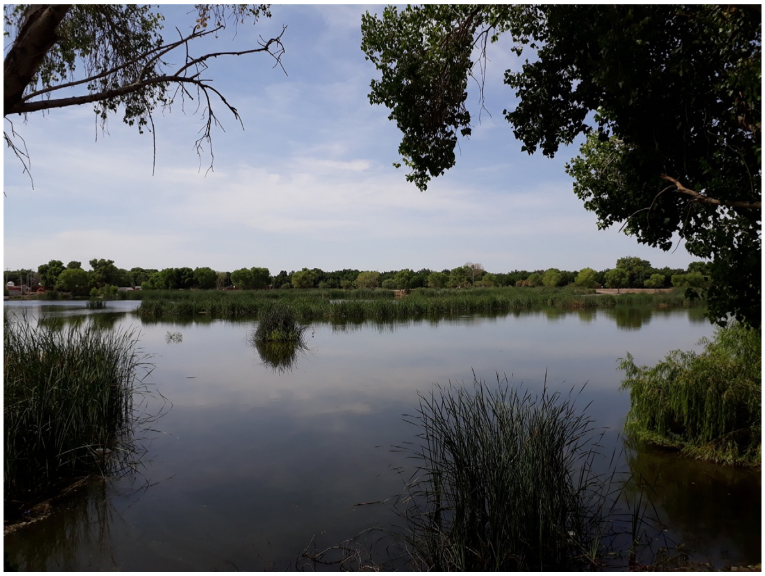

Fig. 4 The declaration of the Meoqui wetland, which lies along the Rio San Pedro (a tributary of the Rio Conchos, which flows into the RGB at Big Bend), as a Ramsar site has spurred the formation of public-private partnerships and attracted outside funding that have greatly helped to protect this critical wetland site for people and wildlife in the long-term. Photo by Alfredo Rodriguez, WWF-Mexico, with permission.

ecological values of the Chihuahuan Desert. The conservation focus of each of these areas differs with geography, biotic communities and the priorities of the people living in these areas. On the U.S. side of the Chihuahuan Desert, there are numerous conservation and recreation areas managed by the Forest Service, National Park Service, Fish and Wildlife Service, Bureau of Land Management as well as areas managed by the states of New Mexico and Texas. For example, across from the expanse of protected areas managed by Mexico in the Big Bend binational region, Big Bend National Park is bracketed by two natural areas managed by the Texas Parks and Wildlife Department: Big Bend Ranch State Park and Black Gap Wildlife Management Area. Together with the protected areas managed across the river by CONANP, the footprint of these protected areas covers over 13,000 ki^2 (5000 mi^2) (Fig. 5). The conservation importance of the RGB through the Chihuahuan Desert is further recognized by the river's designation as Wild and Scenic (managed by the National Park Service on U.S. side of the river) and Monumento Natural (managed by CONANP on the Mexican side of the river).

Local—Examples From the Field

Working with private landowners

Given the amount of land in the Chihuahuan Desert that is in private hands, collaboration between the private sector and the conservation community is key to protecting the Chihuahuan Desert. Two efforts are highlighted, below, to offer a taste of the plethora of community-based conservation work that is taking place in this remarkable ecoregion.

Working with ranchers to stem soil erosion in the upper Rio Conchos

Overgrazing, urban development, expansion of agricultural, road development, mining, amongst other human interferences have altered vegetation cover and accelerated soil erosion and loss from upper watershed surfaces (Rodríguez-Pineda et al., 2017). In Mexico, federal agencies, and such nongovernmental organizations like World Wildlife Fund, Mexico (WWF-Mexico), have worked collaboratively with private landowners to implement a variety of conservation efforts to stem soil erosion. For example, working with upland ranchers and farmers (those without irrigation rights), this collaborative public-private partnership constructed berms to slow soil loss on 10,230 ha (25,280 acres) of priority Chihuahuan Desert uplands between 2004 and 2010. A critical part of this effort is to provide ranchers, farmers and ejidatarios (members of communally managed lands known as Ejidos) education and training needed to maintain and expand upon these initial successes (Fig. 6).

Water harvesting with Raramuri communities

To engage local citizens in natural resource conservation efforts, the needs of local citizens need to be addressed, as well. Particularly with regard to economically compromised communities, citizens often do not have the luxury to involve themselves in long-term initiatives when efforts to maintain livelihood can be a day-to-day struggle. However, if projects can meet immediate socioeconomic needs, a foundation for longer term and more natural resource conservation focused efforts can be established. An example of this trajectory is an effort implemented by WWF-Mexico to install water harvesting projects (collecting water off of roof tops for family use and home gardens) in several Raramuri communities in the Sierra Tarahumara mountains of the southwestern portion of the

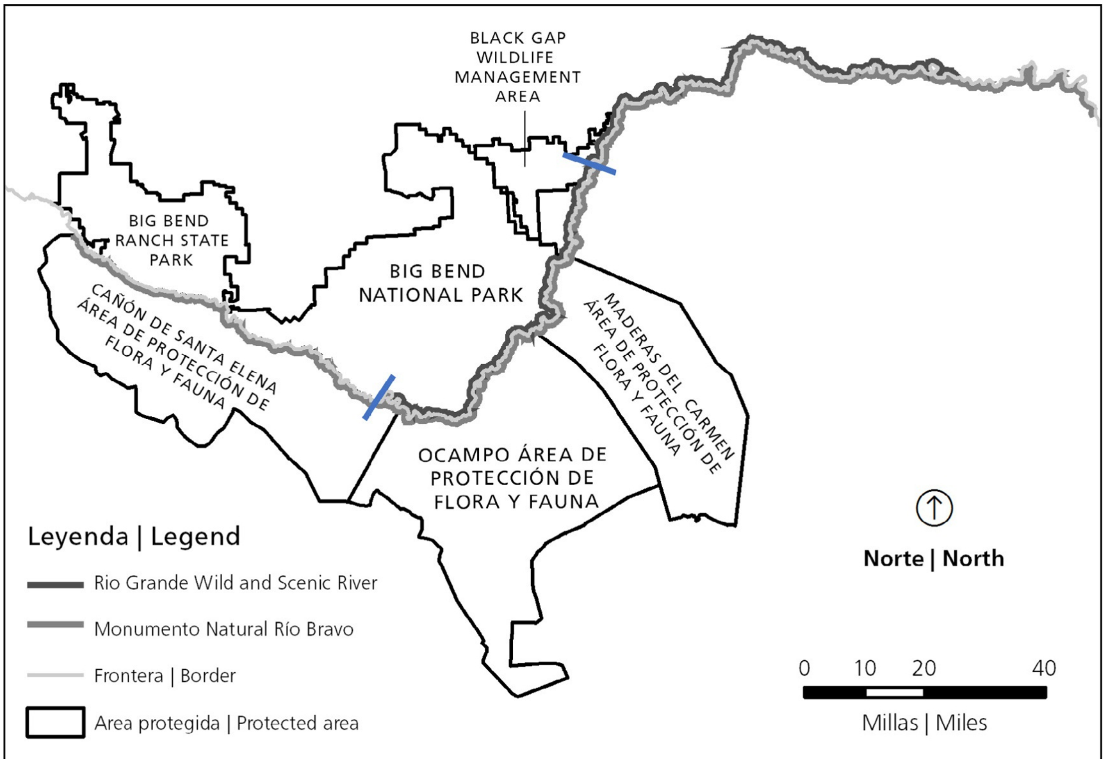
BLACK GAP WILDLIFE MANAGEMENT AREA
BIG BEND RANCH STATE PARK
BIG BEND NATIONAL PARK
CAÑÓN DE SANTA ELENA ÁREA DE PROTECCIÓN DE FLORA Y FAUNA
MADERAS DEL CARMEN ÁREA DE PROTECCIÓN DE FLORA Y FAUNA
OCAMPO ÁREA DE PROTECCIÓN DE FLORA Y FAUNA
Leyenda | Legend
Rio Grande Wild and Scenic River
Monumento Natural Río Bravo
Frontera | Border
Area protegida | Protected area
Norte | North
0 10 20 40
Millas | Miles

Fig. 5 Map of the binational Big Bend region of the Chihuahuan Desert, whose central feature is a core of protected areas on both sides of the international border that cover over 13,000 ki^2 (5000 mi^2). Binational restoration efforts have improved biophysical conditions along over 160 km of the RGB (the reach between the two hash marks). See ‘Protecting Freshwater Ecosystems,’ below. Map by Marie Landis, Big Bend National Park.

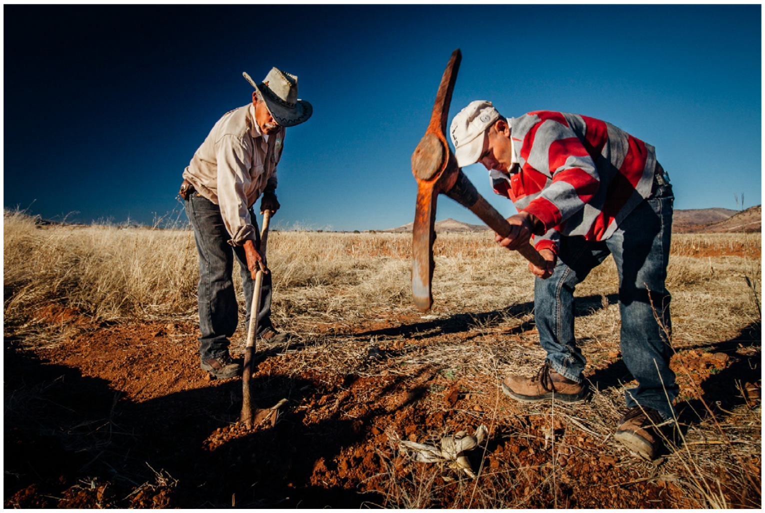

Fig. 6 Ranchers in the state of Chihuahua install berms along contour lines to increase water retention and stem soil loss. Photo by Day’s Edge Productions.

state of Chihuahua. In and of itself, this effort has little to do with protecting Chihuahuan Desert natural resources and all to do with benefiting the well-being of the Raramuri communities. Yet, such community-based work is instrumental in fostering a variety of long-term grassland and forest restoration efforts in the subbasins that are part of the Raramuri lands. In addition, water harvesting efforts that began with Raramuri communities are now being replicated in other parts of the Chihuahuan Desert (Fig. 7). The bottom line: such community-based efforts are key to private engagement and toward expanding conservation efforts for greater impact.

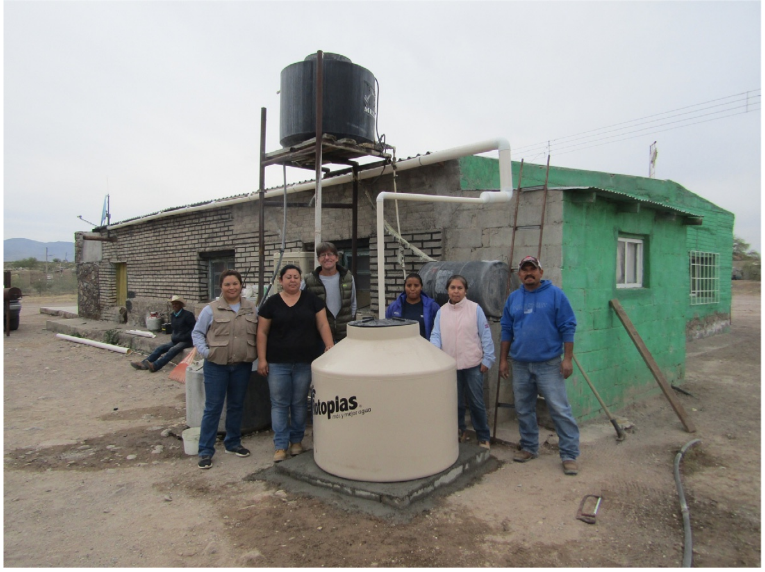

Fig. 7 Community-based water harvesting projects such as this one in the community of Paseo de San Antonio (near the U.S.-Mexico international border) stemmed from work conducted with Raramuri communities and provides great incentive for larger community involvement in a range of conservation activities. Photo by Javier Ochoa-Espinosa (Área de Protección de Flora y Fauna Maderas del Carmen).

Understanding and managing changing fire regimes

Managers throughout the region agree that reducing the risk of destructive, uncharacteristically severe forest wildfires is a priority. Although the actions needed to mitigate this risk vary with location, the reduction of tree density and surface fuel loads is often put forward as central objectives (CEC, 2014). To accomplish these objectives, prescribed fire, forest thinning, and their combination are some of the few tools managers have to manage the surface and aerial fuel array in fire-adapted forests (Schwilk et al., 2009; Stephens et al., 2009).

Studies on the results of fuels hazard mitigation treatments have been carried out at a range of sites on the US portion of the Chihuahuan Desert, including the Guadalupe Mountains, Davis Mountains, and Big Bend National Park (Poulos and Gatewood, 2013; Poulos et al., 2019a,b). Results from these studies suggest that there are tradeoffs associated with carrying out either prescribed fire, forest thinning, or their combination. Resource managers throughout the region need more comprehensive information about the consequences of alternative management practices involving fire and mechanical/manual fuel reduction treatments in a range of upland sites in the Chihuahuan Desert. Work to this end is ongoing, and mangers are continuing to experiment with fuel reduction activities at all of the aforementioned sites with the goal reducing management risk and uncertainty of catastrophic wildfire to the greatest degree possible.

Protecting freshwater ecosystems

Native fish conservation

In spite of being well-adapted, many native freshwater fish of the Chihuahuan Desert are threatened or endangered, often due to human actions that have altered streamflow and their natural habitat. There are several efforts that are specifically aimed at protecting the native freshwater fish of the Chihuahuan Desert. On the U.S. side of the ecoregion, stream restoration efforts have been conducted to benefit the threatened Pecos Bluntnose Shiner (*Notropis simus pecosensis*) (Hoagstrom et al., 2008) and to reintroduce the Rio Grande silvery minnow (*Hybognathus amarus*) (USFWS, 2010; Edwards, 2005). In Mexico, the waters of the Rio Conchos provide life to a great diversity of native freshwater fish, many of which are endemic (De la Maza-Benignos, 2009). In the upper part of basin, the Conchos Trout (*Oncorhynchus* sp.) is the only native Mexican trout known from an Atlantic drainage (Hendrickson et al., 2006). WWF-Mexico in collaboration with federal agencies and local communities are protecting the last known refuges of this species through a combination of watershed-based upland and bottomland conservation actions.

An essential part of this work is protecting the streamflow that the Conchos Trout and other native fish depend on for their survival. In pursuit of this goal, 10 sites in the Rio Conchos basin were selected as priorities to define federally mandated environmental flow prescriptions that will protect water needs of local citizens as well as native aquatic species, including the Conchos Trout. Although challenges to protecting streamflow for environmental purposes are formidable, progress is occurring. For example, the large irrigation district of Delicias is working to implement environmental flow prescriptions that will be sustainable for both irrigated agriculture and Rio Conchos trout.

One of the most threatened fish of the Chihuahuan Desert (possibly in the world) is the Julimes pupfish (*Cyprinodon julimes*). Rarely more than 5 cm (2 in.) long, the Julimes pupfish lives in hot-spring waters that reach 45.5 °C (114° F), earning it the title of the "hottest fish in the world." The Julimes pupfish is endemic to the hotsprings of the small municipality of Julimes, where a population of several thousand fish—along with a tiny snail that is its main food source—survives in an area of about 745 square meters (8000 sq. ft) (De la Maza-Benignos, 2009) (Fig. 8). To protect the hottest fish in the world, a unique partnership developed between NGOs (Pronatura Noreste and WWF-Mexico), several private foundations, and management agencies. To date, this partnership has realized several key accomplishments that include: (i) restoring suitable habitat for the pupfish; (ii) having the hot springs nominated as a global Ramsar site; and (iii) working within the Mexican National Water Law of 1992 to establish and protect minimum flow requirements for the pupfish.

Binational effort to bring back the Rio Grande/Bravo in Big Bend

A centerpiece of the portion of the Rio Grande/Bravo (RGB) watershed that lies within the Chihuahuan Desert is the remote Big Bend binational area. Three protected areas in the U.S.—Big Bend National Park, Big Bend Ranch State Park, and Black Gap—and three in México—Cañón de Santa Elena, Ocampo and Maderas del Carmen—protect over 1 M hectares (over 3800 mile^2) of relatively intact Chihuahuan desert habitat and a 290 km (180 miles) reach of the Rio Bravo (Fig. 5). With few road access points, this reach of the RGB that passes through this region is considered one of the great wilderness rivers in North America.

As noted previously, by the early 2000s, dense, almost impenetrable stands of giant cane have become established along many streams and rivers of the Chihuahuan Desert, including parts of the RGB in Big Bend. In response, a binational partnership that consists of federal and state land and water managers, nongovernmental organizations, private foundations, businesses, and riverside citizens designed and implemented a restoration program whose aim is to (i) significantly reduce the extent and dominance of giant cane along the Big Bend reach of the river; (ii) monitor results and conduct needed science; and (iii) work with land and water management agencies to improve water management that better reflects the needs of native stream ecosystems and the riverside communities along this critical binational river (Fig. 9). To date, the binational partnership has restored over 160 km (100 miles) of both sides of the Rio Grande/Rio Bravo in Big Bend.

Working with ranchers to protect key Rio Grande/Bravo tributaries

Restoring native aquatic and riparian habitat along tributaries of the RGB has become an important binational conservation priority. Given that many of these streams are on private lands, working with ranchers on solutions that will benefit them as well as the environment is essential. In Mexico, CONANP is working with local communities to bring back several key small tributaries of the RGB that have been degraded by mining, overgrazing, pollution, and introduction of nonnative species. The diverse conservation campaign that CONANP has launched includes environmental education (with particular attention on the importance of water and water harvesting strategies), scientific studies on current conditions and trends, and restoration and monitoring, An example of this response is restoration work along the streams of San Carlos and San Antonio streams, which are tributaries of the RGB and together drain an area of roughly 2000 sq. km (772 sq. miles). Restoration along these tributaries has centered on controlling nonnative plants and fish (e.g., saltcedar (*Tamarix* spp.) and the plains killfish (*Fundulus zebrinus*)), planting native riparian trees, and working with local communities to improve livestock management and waste water treatment. Similar work is also being conducted along tributaries in the U.S. portion of the Chihuahuan Desert.

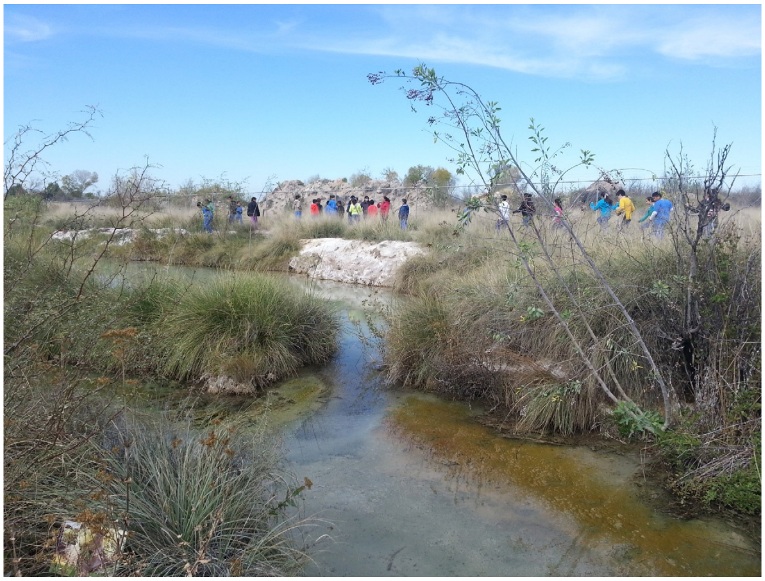

Fig. 8 Visitors tour the Julimes hot springs. Ecotourism is a key component of this community-based effort to protect the Julimes pupfish in the long-term. Photo by Alfredo Rodriguez (WWF-Mexico).

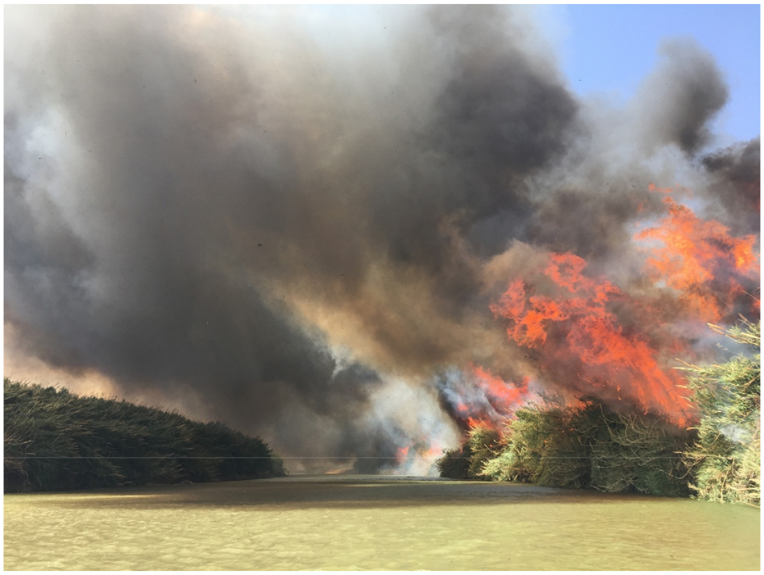

Fig. 9 Prescribed burn of dense stands of giant cane along the Rio Grande/Bravo in the binational region of Big Bend (right). Binational efforts to improve conditions along the RGB have been conducted along over 160 km (100 miles) and demonstrate that stream restoration in complicated sociopolitical landscapes is not only possible but can produce substantial win-wins for people and the environment. Photo by Kelon Crawford, RGSSS.

Looking to the Future

The Chihuahuan Desert embodies the challenges of a new era in which the unsolved natural resource issues of the 20th century meet the 21st century's global challenges of security, development, and conservation. It is a place of clashing cultures, economic dynamism, political strife, and a natural environment under increasing pressure. It is also a place of rare opportunity, where a confluence of political will, scientific and policy advances, stakeholder engagement, and a unique mosaic of conservation efforts on both sides of the US/Mexico border have set the stage for adaptive watershed management that integrate social and ecological resilience to overcome water scarcity and support the development of a green economy. But the Chihuahuan Desert is a very big place. Where best to concentrate our efforts across this expansive ecoregion? Fortunately, social and political events, as well as the collective experiences from a range of past and on-going conservation efforts can help point us in the right direction. As we look to the future, key conservation priorities for the Chihuahuan Desert should include the following considerations:

(1) *Stop the Bleeding*! Whether we are considering the Chihuahuan Desert's montane forests, desert scrublands, grasslands, or fresh water ecosystems, the first rule of conservation is the same: identify and eliminate (or reduce the impacts of) the main stressors that are causing ecosystem decline. Our ability to do this may be the most important fork in the conservation road. If the major stressors cannot be addressed, it is likely that we will be left working on the fringes, making only minor progress toward real improvement. On the other hand, if a main stressor is eliminated or its impacts are significantly reduced, there may be great potential for dramatic improvement of ecologic conditions at a much larger scale with consummate win-wins for people and wildlife.

(2) *Scaling Up for Greater Impact*: There are parts of the Chihuahuan Desert where the pieces are in place for a much more ambitious effort to address the environmental, social and economic challenges at landscape scale. One good example is in the Big Bend region where binational restoration work along the RGB coupled with protected areas on both sides of the river (both sides of the international border) offer great opportunities for expansion. How such conservation/restoration expansion will be funded is a key question. One funding avenue that needs to be explored is how future conservation and restoration actions could be supported by binational ecotourism, which could increase under a regional strategy that aligns with conservation goals identified by agency managers and local communities. In general, ecotourism could be enhanced with greater attention to public outreach that emphasizes the importance of the Chihuahuan Desert as a stopover and/or destination location for such species as land bird migrants (Macías-Duarte et al., 2009; Finch and Yang, 2000) and the Monarch butterfly (Jepsen et al., 2015) that are appealing to the public and offer the potential of bringing in much needed conservation funding.

(3) *Strengthen Support of Existing Federal and State Protected Areas*: As noted earlier, numerous state and federal protected lands are scattered throughout the Chihuahuan Desert. Regardless of where these protected areas occur and the entity that manages them, cuts in staff and resources over the years have left many in a precarious position that threatens their ability to realize their conservation mission and goals. Strengthening of federal (as well as state) conservation budgets on both sides of the border has to be a priority.

(4) *Expand Public-Private Partnerships and Binational Collaboration*: With the above point made, it is also important to note that governments will not be able to address threats to the Chihuahuan Desert ecoregion on their own. Although diverse and

numerous, the total area under federal or state protection is miniscule when compared to the entire footprint of the Chihuahuan Desert. Therefore, one of the keys to protecting the natural resources of the Chihuahuan Desert is alignment, cooperation and collaboration between the conservation community, the private sector (communities, Ejidos, private landowners, businesses, farmers, and ranchers), land and water managers, and academic institutes. Building off of momentum gained from public-private partnerships that have already been created and have a track record of conservation accomplishments is key. The diverse mix of agencies, organizations, institutes, businesses, and communities that are working together to protect the natural resources along the border region provides an example of what is needed for the future to protect the Chihuahuan Desert ecoregion as a whole.

(5) *Protect Biodiversity Hotspots*: Biodiversity hotspots in the Chihuahuan Desert have been identified and should rise to the top as conservation priorities. These hotspots include:

- *Key mountain ranges*: Recent research has identified key mountain ranges in the Chihuahuan Desert that are characterized by high tree species richness—likely due to the complex topography that provides a wide-range of environmental conditions for tree growth—that warrant greater conservation attention owing to both the biodiversity they support and the threats they face (CEC, 2014; Villarreal-Quintanilla et al., 2017).
- *Grasslands*: Given the high percentage of private lands in this ecoregion, protecting intact grasslands and restoring damaged ones will hinge on partnerships with private landowners. In Mexico, more emphasis needs to be placed on working with ejidos (communal land holdings) and Mennonite communities that farm areas that were previously grassland, and/or adjacent to native grasslands. The goal has to be to find ways to manage the land that support the conservation of biodiversity while still meeting the land and food needs of citizens. Past work has identified several grassland dominated areas with particularly high plant diversity (Dinerstein et al., 2000).
- *Wetlands, Streams, and Springs*: Protecting the Chihuahuan Desert's fresh water ecosystems means protecting the water resources that sustain them. The saying, 'water is for fighting, whiskey is for drinking,' underscores the scramble for water between countries, states, agriculture and municipalities that is already occurring in the Chihuahuan Desert as the gap between water supply and demand continues to grow. The environment will be the inevitable loser if we are not able to protect and dedicate water for native ecosystems. Recent binational forums have identified a diversity of efforts already underway to improve management and protect flow for native species and riverside citizens (Briggs et al., 2018). But, more needs to be done to learn from these efforts for greater future impact.

In addition, protecting key wetland, stream, and spring complexes need to be a priority. For example, the wetland complexes in Cuatro Ciénegas has long been held up as a conservation priority. Although parts of this critical wetland complex lie within areas managed by CONANP, the battle over water will require strong public-private partnerships to protect water supplies needed to maintain these critical wetlands in the future.

(6) *Expand Natural Resource Monitoring*: The uncertain future of the integrity of the Chihuahuan Desert ecosystem underscores the importance of generating baselines for monitoring changes in natural resource conditions of priority conservation targets. Conservation biologists, restoration ecologists, natural resources managers, and local land owners need benchmarks for documenting changes in ecosystem structure and function and for defining best management practices. Although much more needs to be done in this regard, there are on-going monitoring efforts that are documenting hydroecologic vital signs amongst diverse priority conservation areas on both sides of the US-Mexico Border. For example, a 149-plot monitoring network has been established that spans the range of key Chihuahuan Desert ecosystems to evaluate the health and integrity of the region based on photography and vegetation surveys (Poulos and Lozano-Cavazos, 2014). But, more needs to be done and greater attention needs to be given to collecting baseline information and monitoring changes in natural resource conditions and the threats that are driving change.

(7) *Taking Stock of Past Conservation Efforts*: Numerous conservation efforts of different scales have been implemented by a variety of players across the Chihuahuan Desert ecoregion. The results of such efforts provide an opportunity to take stock and learn from them for future benefit. Pertinent questions, include: How well did these efforts meet their conservation/restoration objectives and what were the key lessons learned from them? What types of efforts and/or strategies and/or mix of entities were effective in meeting conservation objectives? Are the results of these efforts viable in the long-term? Selected examples of past or on-going conservation efforts that we should take stock of are highlighted, below:

- Community-based conservation: As mentioned previously, numerous community-based efforts have taken place in the Chihuahuan Desert (e.g., Raramuri communities highlighted, above) that offer a wealth of experience on involving municipalities, Ejidos, local communities, and the agricultural sector in conservation efforts that produces win-wins for people and the environment.
- Restoration of RGB riverine ecosystems: Key lessons learned from collaborative, binational work to bring back aquatic and riparian habitat along the RGB, include the importance of establishing: (i) Strong binational working relationships; (ii) Public-private partnerships; (iv) A mix of near-term tangible conservation objectives while longer term (more difficult) objectives are being pursued. Lessons learned from these initiatives are critical to protecting and bringing back freshwater ecosystems throughout the Chihuahuan Desert.
- Work with ranchers and farmers—On-going conservation work with both of these sectors demonstrates how important their involvement is to protecting the natural resources of the Chihuahuan Desert. Working with ranchers to improve livestock management, slow water and soil runoff, enhance recharge is central to improving grassland conditions in many parts of the Chihuahuan Desert. Working with farmers (as well as water managers) to conserve water and improve the flexibility of water

management will be central to protecting drops for native freshwater ecosystems as well as the livelihoods of Chihuahuan Desert citizens.

(8) Share the Good News and Keep the Momentum Going: Although the people and the natural recourses of the Chihuahuan Desert face many challenges, there is much good news in the form successful conservation projects, partnerships, and binational initiatives. This 'good news' needs to be shared more broadly both within and outside the Chihuahuan Desert. Three examples of efforts conducted to enhance communication, coordination and collaboration toward key conservation goals in the Chihuahuan Desert are highlighted, below:

- A binational forum on water scarcity in the Rio Grande/Bravo basin, which took place in El Paso in 2017, brought together municipalities, farmers, scientists, natural resource and water experts, conservationists, water and land managers, and community leaders to identify strategies to address water scarcity. Priorities and next steps were identified (Briggs et al., 2018);
- The International Boundary Water Commission and its sister agency in Mexico, la Comisión Internacional de Limites y Agua (CILA), routinely hold binational forums on water distribution and management as it relates to the water treaties between the U.S. and Mexico. These forums provide excellent opportunities to identify and move forward on solutions to water scarcity;
- The Rio Grande/Bravo Climate Impacts & Outlook ('The Outlook') monthly newsletter that provides timely climate, weather, and impacts information to stakeholders, researchers, and other interested parties in the Rio Grande/Bravo Basin region of New Mexico, Texas, and Mexico. The Outlook is a product of the North American Climate Services Partnership (NACSP)—an innovative trilateral partnership between the U.S., Mexico and Canada.

References

Abatzoglou JT and Williams AP (2016) Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences* 113(42): 11770–11775.

Bond NR, Lake PS, and Arthington AH (2008) The impacts of drought on freshwater ecosystems: an Australian perspective. *Hydrobiologia* 600: 3–16.

Briggs MK, Barajas IA, Barrios E, Grabau M, Karas B, Langston M, Mahlknecht J, López Pérez M, Radtke J, Roberson A, Rodriguez-Pineda A, Takats J, and Winton K (2018) Water scarcity in the Rio grande/Bravo watershed: challenges and solutions. Results of binational Rio Grande/Bravo Water Forum, El Paso, November 7–8, 2017. Available through World Wildlife Fund-Mexico office, Mexico City or through M.K. Briggs (markkbriggs@gmail.com), 29 pp.

Brush T (2005) *Nesting birds of a tropical frontier—The Lower Rio Grande Valley of Texas.* College Station, Tex.: Texas A&M University Press.

Bureau of Reclamation (BOR) (2013) *Lower Rio Grande basin study. Great Plains Region, Oklahoma-Texas Area Office.* Denver, Colorado: U.S. Department of the Interior.

CEC (2014) *Conservation assessment for the big Bend-Río Bravo Region: A binational collaborative approach to conservation*, 106 pp. Montreal, QC: Commission for Environmental Cooperation.

Cotera M, Guadarrama E, Brenner J, Arango AM, Garcia ME, Bell GP, et al. (2004) Ecoregional conservation assessment of the Chihuahuan Desert. Pronatura, The Nature Conservancy. World Wildlife Fund. https://www.conservationgateway.org/ConservationPlanning/SettingPriorities/EcoregionalReports/Documents/Chihuahuan%20Desert%20Report.pdf.

Cruz-Elizalde R, Ramírez-Bautista A, Johnson J, and Moreno C (2014) Community structure of reptiles from the southern portion of the Chihuahuan Desert Region, Mexico. *North-Western Journal of Zoology* 10: 173–182.

Dean DJ and Schmidt JC (2013) The geomorphic effectiveness of a large flood on the Rio Grande in the Big Bend region: Insights on geomorphic controls and post-flood geomorphic response. *Geomorphology* 201: 183–198.

De la Maza-Benignos M (ed.) (2009) *Los Peces del Río Conchos. Alianza World Wildlife Fund-Fundación Gonzalo Río Arronte*. http://awsassets.panda.org/downloads/peces2010_web.pdf.

Dennison PE, Brewer SC, Arnold JD, and Moritz MA (2014) Large wildfire trends in the western United States, 1984–2011. *Geophysical Research Letters* 41(8): 2928–2933.

Dinerstein E, Olson D, Atchley J, Loucks C, Contreras-Balderas S, Abell R, Iñigo EE, Williams C, and Castilleja G (2000) *Ecoregion-based conservation in the Chihuahuan Desert: A biological assessment.* World Wildlife Fund.

Edwards RJ (2005) *Feasibility of reintroducing Rio Grande Silvery Minnows (*Hybognathos amarus*) to the Rio Grande, Big Bend region, Texas.* Final Report to the U.S. Fish and Wildlife Service.

Everitt B (1993) Channel responses to declining flow on the Rio-Grande between Ft Quitman and Presidio, Texas. *Geomorphology* 6(3): 225–242.

Finch DM and Yang W (2000) Landbird migration in riparian habitats of the Middle Rio Grande: A case study. *Studies in Avian Biology* 20: 88–98. Request pub from rmrspubrequest@fs.fed.us.

Garssen AG, Verhoeven JTA, and Soons MB (2014) Effects of climate-induced increases in summer drought on riparian plant species: A meta-analysis. *Freshwater Biology* 59(5): 1052–1063.

Gómez-Hinostrosa C and Hernández HM (2000) Diversity, geographical distribution, and conservation of Cactaceae in the Mier y Noriega region, Mexico. *Biodiversity & Conservation* 9(3): 403–418.

Grimm NB, Chacón A, Dahm CN, Hostetler SW, Lind OT, Starkweather PL, and Wurtsbaugh WW (1998) Sensitivity of aquatic ecosystems to climatic and anthropogenic changes: The basin and range, American Southwest and Mexico. *Hydrological Processes* 11(8): 1023–1041.

Hendrickson DA, Kuhajda B, Mayden R, Neely D, Propst D, Tomelleri J, and Cutter RF (2006) Conservation of the Conchos Trout: A white paper on history of its discovery, report on its status, and an urgent plea for action. Web available at: https://www.researchgate.net/publication/265113157.

Hernandez HM and Barcenas RT (1995) Endangered cacti in the Chihuahuan Desert: I. Distribution patterns. *Conservation Biology* 9(5): 1176–1187.

Hoagstrom CW, Brooks JE, and Davenport SR (2008) Recent habitat association and the historical decline of *Notropis simus pecosensis*. *River Research and Applications* 24: 789–803.

Jepsen S, Schweitzer DF, Young B, Sears N, Ormes M, and Black SH (2015) *Conservation status and ecology of the Monarch butterfly in the United States*, p. 36. Portland, Oregon: NatureServe, Arlington, Virginia, and the Xerces Society for Invertebrate Conservation.

Johnston MC (1977) Brief resume of botanical, including vegetational, features of the Chihuahuan Desert region with special emphasis on their uniqueness. In: Wauer RH and Riskind DH (eds.) *Transactions of the "Symposium on the Biological Resources of the Chihuahuan Desert region, United States and Mexico", Sul Ross State University, Alpine Texas, 17–18 October 1974.* US Dept. Interior, National Parks Service Transactions and Proceedings Series No. 3, pp. 335–359.

Llewellyn D and Vaddey S (2013) *West-wide climate risk assessment: Upper Rio Grande impact assessment.* U.S. Department of the Interior Bureau of Reclamation.

Macías-Duarte A, Montoya AB, Méndez-González CE, Rodríguez-Salazar JR, Hunt WG, and Krannitz PG (2009) Factors Influencing habitat use by migratory grassland birds in the state of Chihuahua, Mexico. *The Auk: Ornithological Advances* 126(4): 896–905. https://doi.org/10.1525/auk.2009.08251.

McRoberts B and Nielsen-Gammon J (2010) Historic and future droughts in the Big Bend Region of the Chihuahuan Desert. In: *WWF Project Final Report*, p. 254.

Miller RR (1977) Composition and derivation of the native fish fauna of the Chihuahuan Desert region. In: Wauer RH and Riskind DH (eds.) *Transactions of the "Symposium on the Biological Resources of the Chihuahuan Desert region, United States and Mexico", Sul Ross State University, Alpine Texas, 17–18 October 1974.* US Dept. Interior, National Parks Service Transactions and Proceedings Series No. 3, pp. 365–382.

Minckley WL (1984) Cuatro Ciénegas fishes: research review and a local test of diversity. *Journal of Arizona-Nevada Academy of Science* 19: 13–21.

Minckley WL, Meffe GK, and Soltz DL (1991) Conservation and management of short-lived fishes: The Cyprinodontoids. In: Minkley WL and Deacon JE (eds.) *Battle against extinction: Native fish management in the American west*, pp. 247–282. Tucson: University of Arizona Press. 517 + xviii pp.

Montaña C (1990) A floristic-structural gradient related to land forms in the southern Chihuahuan Desert. *Journal of Vegetation Science* 1(5): 669–674.

Nielsen-Gammon J (2008) The changing climate of Texas. www.texasclimate.org/Portals/6/Books/.

North American Bird Conservation Initiative (NABCI) (2016) The State of North America's Birds 2016. Environment and Climate Change Canada: Ottawa, Ontario. 8 pages. www.stateofthebirds.org.

Olson DM and Dinerstein E (2002) The Global 200: Priority ecoregions for global conservation. *Annals of the Missouri Botanical Garden* 89(2): 199–224.

PACP-Ch. (2011) Plan de Acción para la Conservación y Uso Sustentable de los Pastizales del Desierto Chihuahuense en el Estado de Chihuahua 2011–2016. In: Guzmán-Aranda JC, J Hoth y E Blanco (Eds.). Gobierno del Estado de Chihuahua, México.

Pool DB, Panjabi AO, Macias-Duarte A, and Solhjem DM (2014) Rapid expansion of croplands in Chihuahua, Mexico threatens declining North American grassland bird species. *Biological Conservation* 170: 274–281.

Poulos HM and Camp AE (2010) Topographic influences on vegetation mosaics and tree diversity in the Chihuahuan Desert Borderlands. *Ecology* 91: 1140–1151.

Poulos HM and Gatewood RG (2013) Effectiveness of thinning and prescribed fire fuel treatments in Piñon-Juniper Woodlands of the Davis Mountains, West Texas, USA. *Journal of Sustainable Forestry* 32(8): 806–821.

Poulos HM and Lozano-Cavazos EA (2014) *Landscape-level monitoring of priority conservation areas in the Big Bend-Río Bravo region using repeat photography*. Montreal, Canada: Commission for Environmental Cooperation.

Poulos HM, Gatewood RG, and Camp AE (2009) Fire regimes of the pinon–juniper woodlands of Big Bend National Park and the Davis Mountains, west Texas, USA. *Canadian Journal of Forest Research* 39(6): 1236–1246.

Poulos H, Díaz JV, Paredes JC, Camp A, and Gatewood RG (2013) Human influences on fire regimes and forest structure in the Chihuahuan Desert Borderlands. *Forest Ecology and Management* 298: 1–11.

Poulos HM, Barton AM, Berlyn GP, Schwilk DW, Faires CE, and McGurdy WC (2019a) Physiological mechanisms drive post-fire resprouter dominance following high-severity wildfire in an Arizona Sky Island range. *Forest Ecology and Management.* In Review.

Poulos HM, Reemts CM, Gatewood RG, Wogan KA, and Karges JP (2019b) Multiple wildfires with minimal consequences: Low-severity wildfire effects on West Texas piñon-juniper woodlands. *Ecosphere.* In Review.

Prival D and Goode M (2014) A herpetological inventory of Chihuahuan Desert National Parks. In: Hoyt CA and Karges J (eds.) *Proceedings of the sixth symposium on the natural resources of the Chihuahuan Desert region, October 14–17, 2004.* Fort Davis, Texas: The Chihuahuan Desert Research Institute.

Rahel FJ and Olden JD (2008) Assessing the Effects of Climate Change on Aquatic Invasive Species. *Conservation Biology* 22: 521–533.

Rodríguez-Pineda JA, Carreón E, Lafon A, Santos J, and Ruiz R (2017) Cambio de uso de suelo en la cuenca del río Conchos, Chihuahua, México. In: Montero MJ and Hernández OFI (eds.) *Cuenca del Río Conchos: Una mirada desde las Ciencias antes del Cambio Climático*, pp. 157–202. Instituto Mexicano de Tecnología del Agua. ©2017. 267 p.

Sakulich J and Taylor AH (2007) Fire regimes and forest structure in a sky island mixed conifer forest, Guadalupe Mountains National Park, Texas, USA. *Forest Ecology and Management* 241(1–3): 62–73.

Schmidt RH Jr. (1979) A climatic delineation of the 'real' Chihuahuan Desert. *Journal of Arid Environments* 2: 243–250.

Schwilk DW, Keeley JE, Knapp EE, McIver J, Bailey JD, Fettig CJ, Fiedler CE, et al. (2009) The national Fire and Fire Surrogate study: effects of fuel reduction methods on forest vegetation structure and fuels. *Ecological Applications* 19: 285–304.

Stephens SL, Moghaddas JJ, Edminster C, Fiedler CE, et al. (2009) Fire treatment effects on vegetation structure, fuels, and potential fire severity in western US forests. *Ecological Applications* 19: 305–320.

Swetnam TW and Betancourt JL (1990) Fire-southern oscillation relations in the southwestern United States. *Science* 249(4972): 1017–1102.

U.S. Fish and Wildlife Service (USFWS) (2010) *Rio Grande silvery minnow (*Hybognathus amarus*) recovery plan, first revision,* viii 210 pp. Albuquerque, NM.

University of Texas at El Paso (UTEP) Museum website http://museum2.utep.edu/chih/NHCD/herps.htm.

Villarreal-Quintanilla JA, Bartolomé-Hernández JA, Estrada-Castillón E, Ramírez-Rodríguez H, and Martínez-Amador SJ (2017) *El elemento endémico de la flora vascular del Desierto Chihuahuense.* Acta Botanica Mexicana. 118: versión On-line ISSN 2448-7589; versión impresa ISSN 0187-7151.

Westerling AL, Hidalgo HG, Cayan DR, and Swetnam TW (2006) Warming and earlier spring increase western US forest wildfire activity. *Science* 313(5789): 940–943.